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Multi-layered physical parameters govern mercury release from soil, its fate and potential for human health and ecological risk

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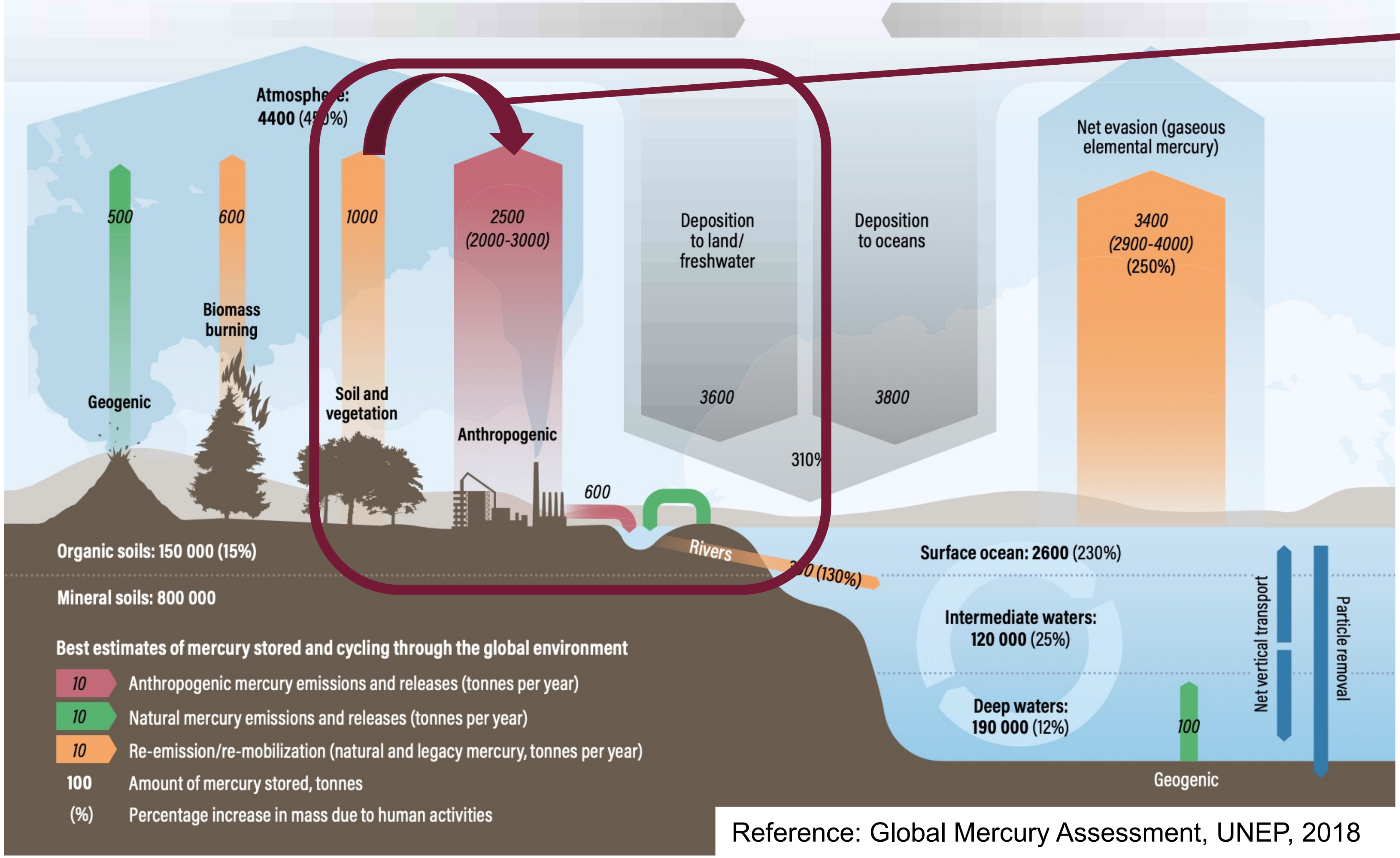
Global Mercury Assessment

Hg global model by UNEP (updated 2018)

- Hg emissions from soil; 1000 tonnes/year, derived from 2500 tonnes/year.



Reference: Global Mercury Assessment, UNEP, 2018

Legacy mercury

- The effects of mercury emitted from human sources in the past, which is still circulating in the biosphere.
- Derived from historical emissions up to the end of the 19th century, mainly from gold, silver, and mercury (cinnabar) mining and refining.
- Difficult to quantify due to frequent soil-ocean-atmosphere transports and highly sensitive to climate change.

Human health risk by mercury (Hg)

Minamata disease in Japan (1956)

- Happened in Japan, 1956
- Damaged by eating mercury bioconcentrated fish.
- Symptoms; remors, muscle rigidity, sensory disturbances and pain, cognitive impairment and memory loss, neuropathy, blurred vision, and skin itching and inflammation
- Recognised patients; 2,265 (1,784 have died)

Japan

Volatile Hg concentration from contaminated soil & groundwater

Ministry of the Environment, JAPAN (2016)

Air; 0.044-0.052 μg/m^3

Groundwater; 0.0016 μg/m^3

Could not explain by saturated vapor pressure

Still unexplained

Few studies can clearly explain Hg emission.
Need to clarify the relationship between Hg emissions and environmental factors.

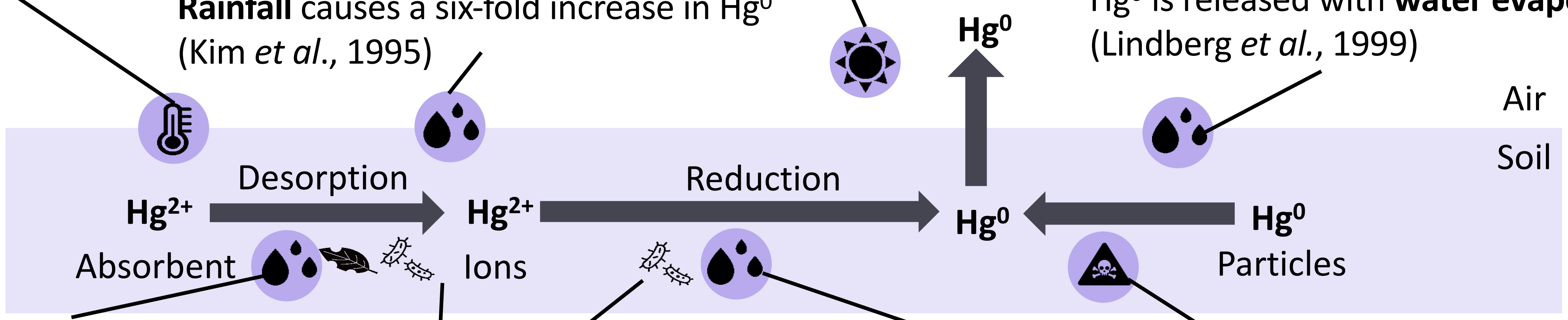
Influence of factors studied in previous studies

The higher **temperature**, the more volatile Hg^0
(Marumoto *et al.*,2005)

Sunlight promotes reduction to Hg^0
(Sizmur *et al.*,2017)

Rainfall causes a six-fold increase in Hg^0
(Kim *et al.*, 1995)

Hg^0 is released with **water evaporates**
(Lindberg *et al.*, 1999)



Dissolved **organic matter** facilitates the desorption of Hg^0
(Yang, *et al.*, 2008)

merB ： Break C-Hg bond
merA ： Promotes $Hg^{2+} \rightarrow Hg^0$ reduction
(Silver *et al.*,1996)

Water saturation inhibits oxygen exchange, creates **reducing atmosphere**
(Gustin *et al.*,2005)

Hg^0 fluxes from contaminated sites are 10 times higher
(Pannu *et al.*, 2014)

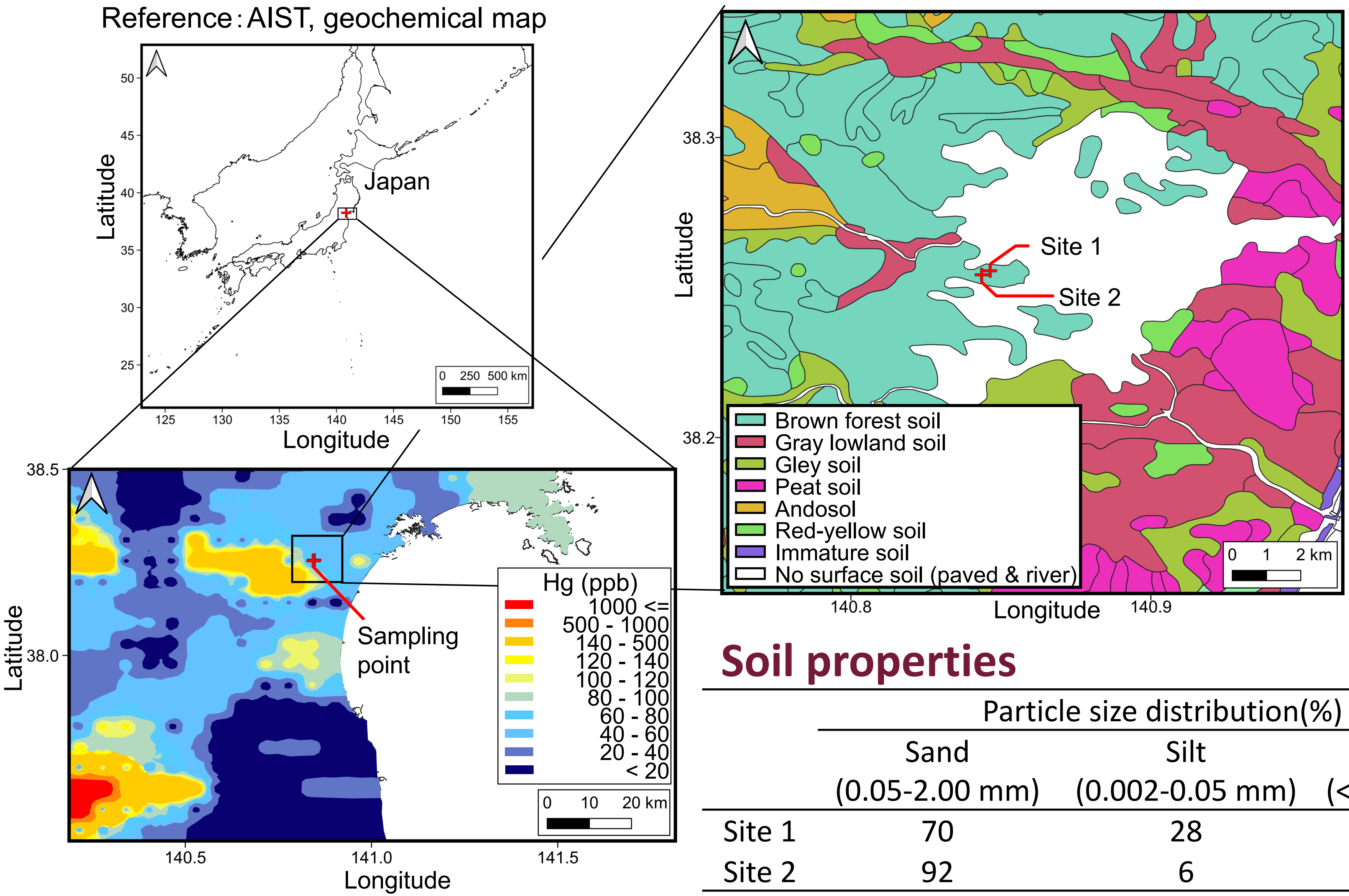
- It is not known which factors drive GEM (gaseous elemental mercury) flux and how to control conditions so as to suppress Hg emission from soil.

Study objectives To investigate the main environmental factors influencing Hg release from soil

taking into account factors previously identified but not comprehensively interpreted

Methodology

On-site measurement at forest Site1 and non-forest Site2

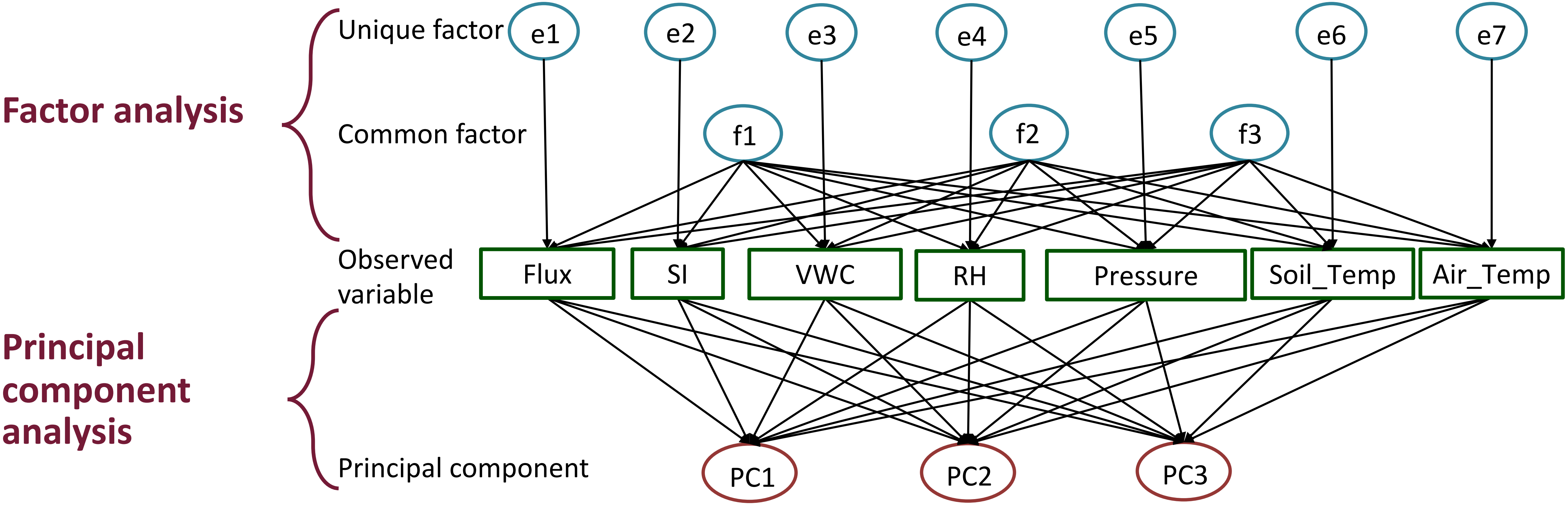


- Transparent chambers were directly covered with soil and gaseous Hg^0 concentrations were measured.
- Aeration collected at a flow rate of 0.3 L/min for 10 minutes ×6 times for 1 cycles.
- Solar irradiance (SI), volumetric water content (VWC) atmospheric pressure, atmospheric relative humidity (RH) and temperature and soil temperature were measured.

Soil properties

	Particle size distribution(%)			Particle texture	IL(%)	T-Hg[mg/kg]
	Sand (0.05-2.00 mm)	Silt (0.002-0.05 mm)	Clay (<0.002 mm)			
Site 1	70	28	2	Sandy loam	11.17	0.09
Site 2	92	6	2	Sand	8.18	0.07

Statistical analysis methodology



Observed data normalisation → Verification of sample validity by Kaiser-Meyer-Olkin → Create Pearson's correlation coefficient matrix → Number of components & factors determined by scree plot

Site 1: KMO=0.53 ○
Site 2: KMO=0.68 ◎

Decided 3 components & 3 factors.

Principal component analysis results

Explain

PC1

: weather condition & flux

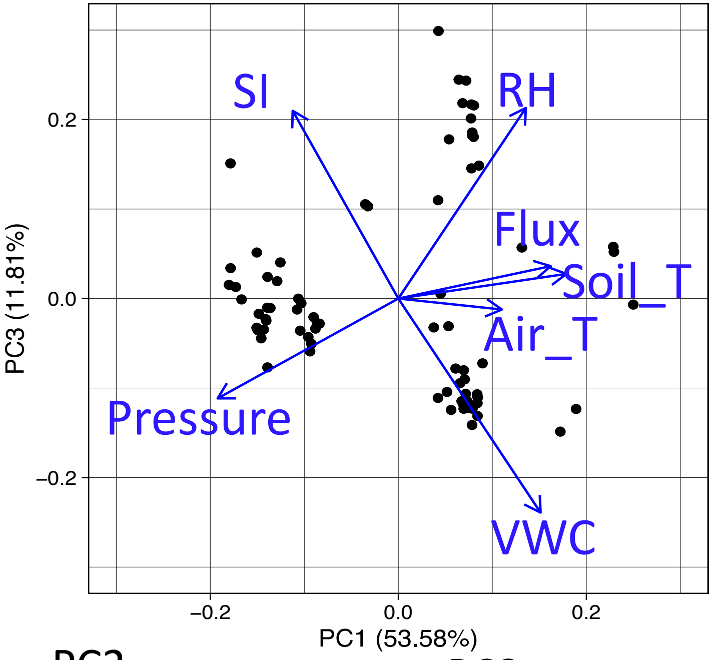
PC2

: atmospheric condition

PC3

: water vapor generation

Site 1



Explain

PC1

: weather condition & flux

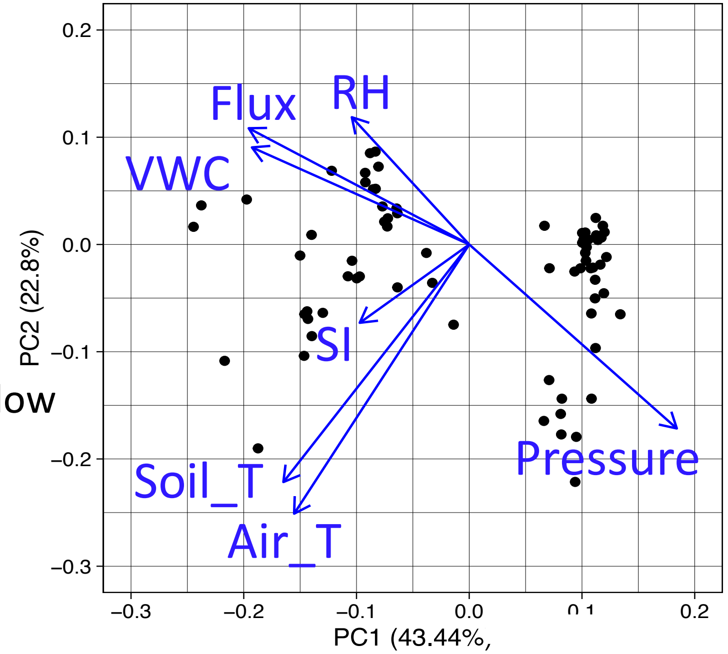
PC2

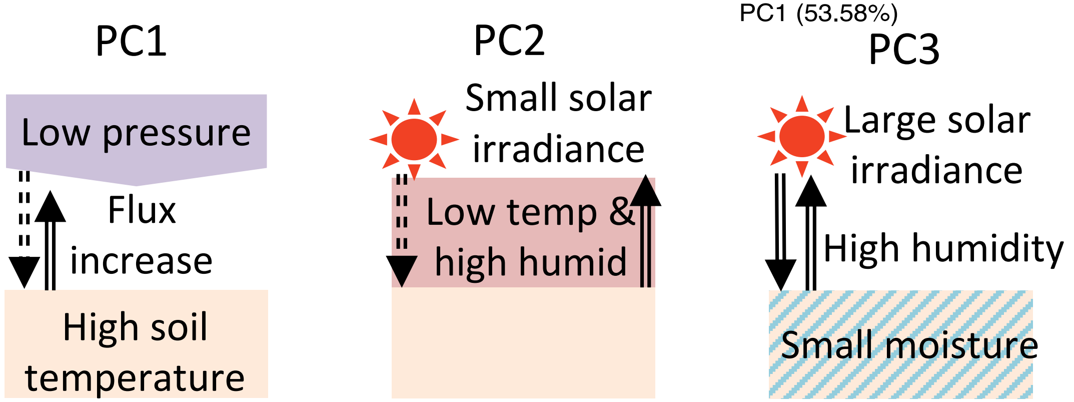
: temperature under low pressure

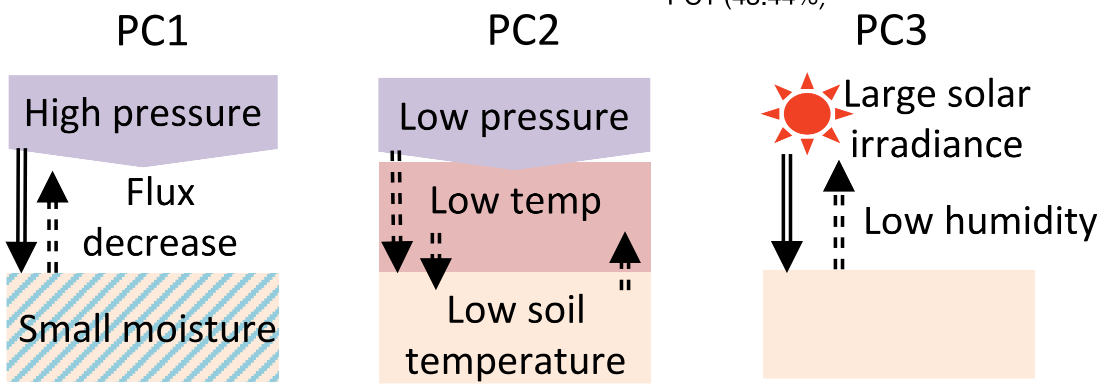
PC3

: atmospheric condition

Site 2







Hg^0 flux is related to the magnitude of the **atmospheric pressure** and **soil temperature**.

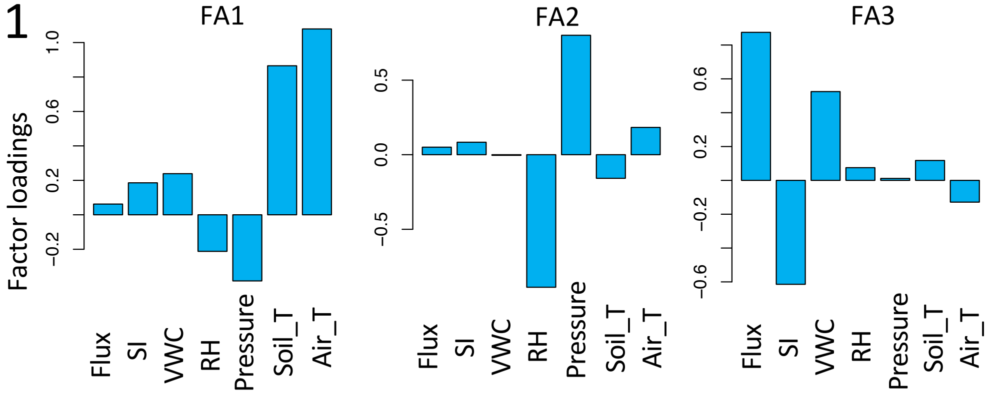
Flux is affected by **volumetric water content** and **atmospheric pressure**.

Factor analysis results

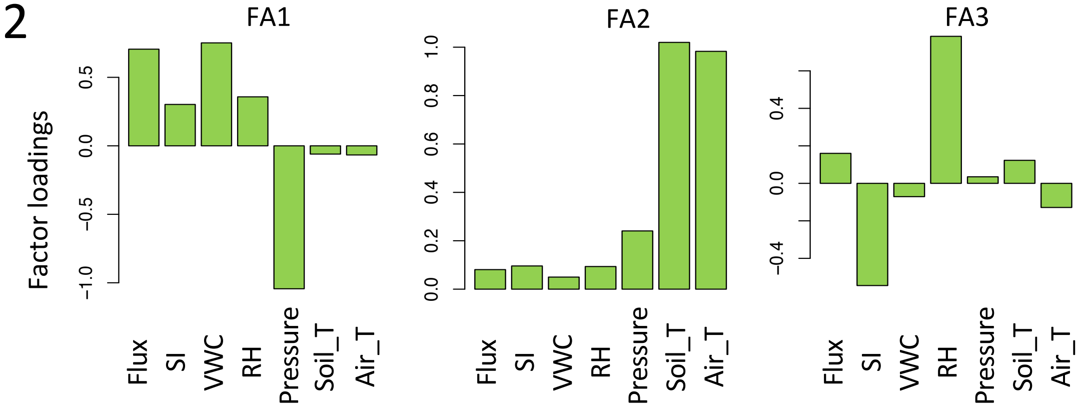
Extraction: **maximum likelihood method**, principal factor, generalized least-squares, weighted least-squares

Rotation: None, 〈orthogonal ; varimax, quartimax, bentlerT, varimin〉,
〈oblique ; **promax**, oblimin, bentlerQ, simplimax, cluster, geominQ〉

Site 1



Site 2



	FA1	FA2	FA3	h^2
Flux	0.06	0.05	**0.87**	**0.75**
SI	**0.19**	0.08	**-0.61**	0.39
VWC	**0.24**	0.00	**0.52**	0.44
RH	**-0.21**	**-0.89**	0.08	**0.79**
Pressure	**-0.38**	**0.80**	0.01	**1.00**
Soil temp	**0.87**	**-0.16**	**0.12**	**1.00**
Air temp	**1.08**	**0.18**	**-0.13**	**1.00**

Flux; High commonality(h^2)

→ strongly influenced by **solar irradiance** & **volumetric water content**

	FA1	FA2	FA3	h^2
Flux	**0.71**	0.08	**0.16**	0.58
SI	**0.30**	0.10	**-0.55**	0.42
VWC	**0.75**	0.05	-0.07	**0.60**
RH	**0.36**	0.09	**0.78**	**0.77**
Pressure	**-1.04**	**0.24**	0.03	**0.95**
Soil temp	-0.06	**1.02**	**0.12**	**1.00**
Air temp	-0.07	**0.98**	**-0.13**	**0.95**

Almost the same as for principal components

→Good data coherence.

→ strongly influenced by **volumetric water content** and **atmospheric pressure**.

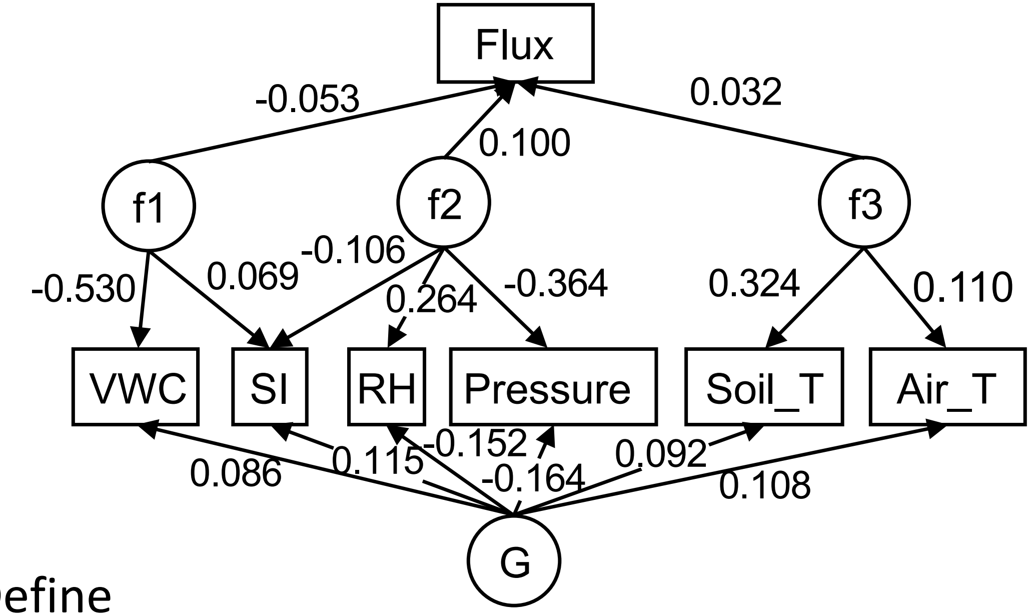
Interpretation by Structural equation modeling

Site 1

f1 =~ Solar + VWC
f2 =~ RH + Pressure + Solar
f3 =~ Soil + Air

G ~Solar + VWC + RH
+Pressure + Soil + Air

Flux ~ f1 + f2 + f3



The numerical index criteria

Chi-square p-value: 0.247 ○
CFI(Comparative Fit Index)=0.999 ◎
TLI(Tucker-Lewis Index)=0.988 ◎
BIC(Bayesian information criterion)
=-402.043 ◎
SRMR(Standardized Root Mean-Square Residual)=0.023 ◎

Site 2

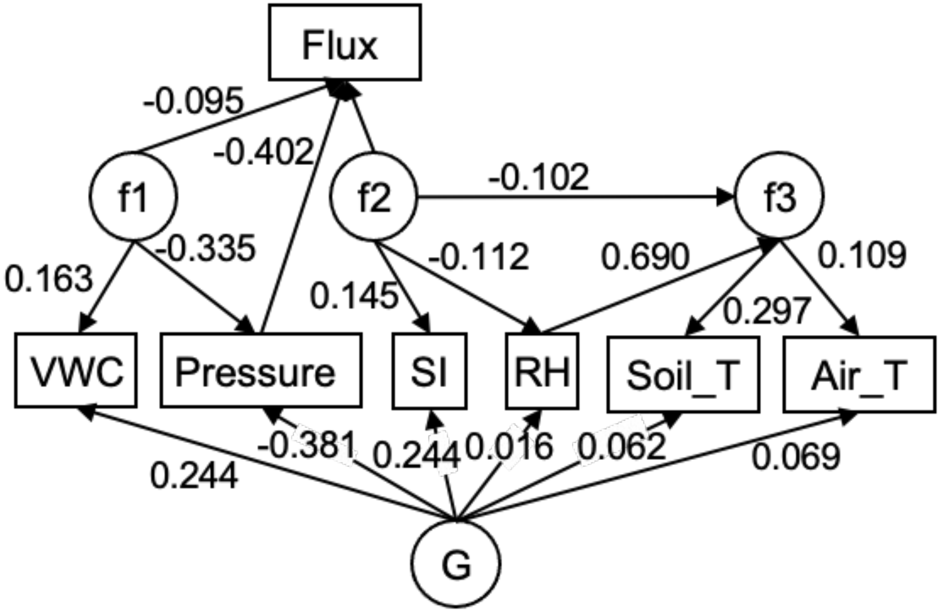
f1 =~ VWC + Pressure
f2 =~ RH + Solar
f3 =~ Soil + Air

G ~Solar + VWC + RH
+Pressure + Soil + Air

G ≈ 0 · f1 + 0 · f2 + 0 · f3
〈Orthogonal to the latent variable〉

Flux ~ f1 + f2 + Pressure

=~ Define
~ Regress
≈ Covariate



The numerical index criteria

Chi-square p-value : 0.228 ○
CFI=0.997 ◎
TLI=0.973 ◎
BIC=-353.105 ◎
SRMR=0.038 ◎

Conclusions

- The relationship between mercury emissions and environmental parameters is summarised and meteorological factors affecting mercury emissions were identified.

- The magnitude of mercury fluxes is directly related to solar irradiance, volumetric water content and atmospheric pressure (defined primary causality). Mercury flux changes with air and soil temperature, and humidity (defined secondary causality).